

3D Analysis of Trihedral Reflection Based on SAR Simulation Methods

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Abstract

Simulation of artificial reflectivity maps supports the interpretation of high resolution SAR images in the azimuth-range plane. Nonetheless, simulation in 3D is mandatory in order to localize and identify salient point scatterers which, for instance, are analyzed for detecting deformation signals by Persistent Scatterer Interferometry. This paper presents first results of a 3D SAR simulation approach based on Ray Tracing methods. Within an urban scene, two different kinds of trihedrals detected and are analyzed for identifying their backscattering surfaces and the corresponding focused intensity contributions. Besides corner reflectors related to real building corners, the appearance of artificial corners inside buildings is confirmed by simulation methods.

1. Motivation

Current space borne SAR sensors provide data with a spatial resolution of below 1 m in spotlight mode. The number of dominant point scatterers increases significantly compared to SAR sensors of moderate resolution [1]. Since buildings now are represented by a high number of scatterers, deformations may be observed for single objects of interest within urban areas [2]. However, as well in the case of high resolution SAR data, interpretation of SAR image features remains challenging due to geometrical effects in range direction [3]. Thus, gaining knowledge about the nature of strong point scatterers is challenging, especially in the case of multiple reflections appearing in urban areas.

2D SAR simulation on a geometrical basis supports the interpretation of scattering effects in the azimuth-range plane. 3D SAR simulation following multiple reflections in space helps localizing and identifying dominant point scatterers in azimuth, range, and elevation. Hence, separation of several scatterers within one SAR image pixel, e.g. by means of SAR tomography, may be supported. Separation of contributions corresponding to real and artificial building corners help making one step forward towards understanding the characteristics of signals used for monitoring urban objects, e.g. as analyzed by Persistent Scatterer Interferometry (PSI) [4].

The paper is structured as follows. Section 2 introduces the characteristics of the proposed SAR simulation approach and presents enhancements to the simu-

lation concept required for providing 3D results presented in this paper. Section 3 shows first results of the 3D analysis of trihedrals detected in an urban scene. Finally, conclusions are drawn and an outlook into future work is given in Section 4.

2. Simulation Concept

2.1 SAR simulation based on Ray Tracing algorithms

The 3D analysis of scattering effects presented in this paper is based on adapted Ray Tracing algorithms [5] provided by the open-source software POV Ray [6]. 3D models of urban scenes are illuminated by an artificial SAR sensor in order to localize intensity contributions in azimuth, range, and elevation. The virtual SAR sensor is considered as a scanner with orthographic projection in azimuth and elevation for a local urban scene with limited extension in elevation. SAR signals are approximated by rays and followed through the 3D site scene. Basically, the simulation concept is composed of three parts. First, a modelling step is required for the purpose of creating the 3D site scene, defining surface backscattering characteristics and introducing a virtual SAR sensor. Second, following rays through the 3D scene is conducted by ray tracing algorithms adapted to SAR geometry. Finally, intensity contributions detected in the scene are used for creating artificial reflectivity maps or analyzing elevation data by means of slices in elevation [7]. In-

tensity contributions may be assigned to different image layers according to bounce level information (number of reflections) provided by the simulator. Separation of several scatterers within the same resolution cell is enabled, e.g. for the purpose of providing a-priori knowledge for SAR tomography [8]. Generally, the focus is on geometric correctness of multiple reflections at the cost of radiometric reliability due to simplified reflection models. The quality of simulation results mainly depends on the geometrical quality of 3D models used as simulation input.

2.2 Identification and localization of salient scatterers

So far, analysis of simulated elevation data has been conducted by creating 2D slices in either azimuth-elevation or range-elevation planes [7]. In this paper, the visual representation of simulation results is enhanced to three dimensions. The basic concept is presented in the following.

In order to identify backscattering surfaces contributing to salient pixels in SAR images, intersection points of the corresponding signals with the 3D site scene have to be visualized. The required 3D coordinates of the intersection points are derived during the sampling step, i.e. by means of ray tracing. Single pixels of interest can be selected within the simulated reflectivity map (see Section 3). Afterwards, intersection points are extracted according to the chosen image pixel and are mapped back into the given 3D model of the urban scene.

Intersection points detected within the 3D site scene indicate the effective area contributing to the reflection effect. For instance, the area covering a corner reflector – mandatory for evaluating the backscattered intensity – is indicated by displaying the extent of the corner reflector's backscattering surfaces (see Figure 1) and corresponds to investigations published by Sarabandi and Chiu [9]. Moreover, the density of intersection points gives knowledge about the sampling density used during ray tracing. This might be of special interest for building features like balconies or windows.

As mentioned above, the SAR simulator provides intensity contributions focused in azimuth, range and elevation. For instance, phase centers of specular corner reflectors appear as points, i.e. as imaged from an ideal SAR system having maximum resolution in azimuth, range and elevation. Mapping focused points in the 3D site model provides information about the spatial position of scatterers. In order to visualize the position of point scatterers in the 3D site model of the urban scene, the given intensity contributions have to be transformed from the sensor coordinate system into the world coordinate system of the 3D model. Necessary a-priori knowledge is provided by the known SAR sensor position in both coordinate sys-

tems, the local angle of incidence, the heading angle of the SAR sensor and the range coordinates of the intensity contributions.

In Section 3, first results of the 3D SAR simulation approach are presented for an urban test site and different kinds of trihedrals are analyzed by means of two examples.

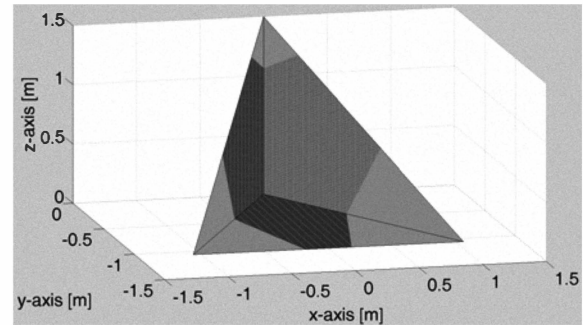


Figure 1: Backscattering surfaces of corner reflector contributing to triple bounce effect (dark gray); bright gray: illuminated 3D model of corner reflector; illumination direction parallel to corner orientation

3 3D Analysis of Trihedrals

3.1 Test study for urban scene

In a test study a 2.5D model of the “Schneiderberg” area in Hanover, Germany, has been used as input for the SAR simulator. Building models are characterized by flat walls and flat or gable roofs. Figure 2 shows an optical view onto the building complex as well as both a TerraSAR-X image and a simulated reflectivity map in azimuth-range geometry. For SAR simulation, heading angle and angle of incidence are defined according to the given TerraSAR-X imaging geometry, i.e. 350.7° and 33.7° , respectively. The artificial reflectivity map mainly contains intensity contributions of bounce levels 1 to 3. For instance, bright linear features are either caused by foreshortening effects at gable roofs or by double bounce at building walls. Bright spots represent triple bounce effects backscattered from trihedrals formed at the intersection area between building walls and the ground. In the following, these bright spots are investigated in more detail.

3.2 Trihedrals – Two Examples

For 3D analysis, two bright pixels causing specular highlights are selected and marked in the simulated reflectivity map (see bottom of Figure 2). Before, the



Figure 2: Location “Schneiderberg”, Hanover, Germany; top: optical image, © Google Earth, center: TerraSAR-X image captured in spotlight mode; bottom: simulated reflectivity map containing two corner reflectors to be analyzed (highlighted by circles), range: top-down

appearance of specular reflection effects in these pixels had been confirmed by means of a binary map provided by geometrical analysis [10].

According to the selected pixel coordinates, the corresponding intersection points are extracted from the output data provided by the SAR simulator and are mapped into the 3D model. The upper part of Figure 3 shows intersection points corresponding to corner No. 1. Lines visible at the 3D model mark boundaries between polygons describing the building shape. Obviously, three walls contribute to the triple bounce effect and form a specular corner reflector. With regard to the phase center of the corner reflector, backscattered intensity contributions are gathered at the same position in space (bottom of Figure 3). Eventually, the

sum of these signal parts yields a strong scatterer clearly visible in the simulated reflectivity map (bottom of Figure 2). The height of the focused point is equal to that of the ground.

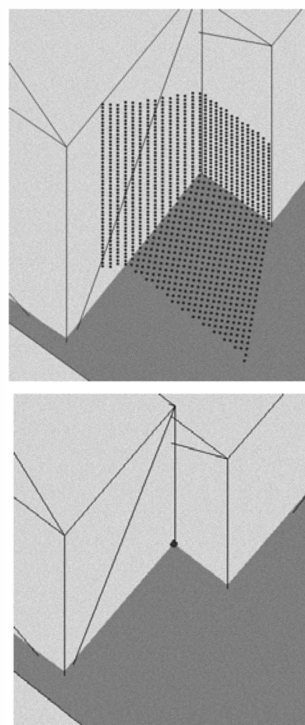


Figure 3: Detected corner reflector showing specular backscattering behavior; top: surfaces contributing to specular highlight represented by dark intersection points; point density indicating the sampling density of the virtual SAR sensor; bottom: simulated phase center of corner reflector; focused corner physically corresponding to building corner

Results for corner reflector No. 2 are presented in Figure 4. In contrast to the corner reflector shown before, the center of the corner is “disturbed” by an additional building edge. Moreover, a small gap between both buildings forming the corner is visible on the right end of the disturbed zone. Nonetheless, all specular reflection contributions are focused at one position in space. Here, the focused point appears inside the building, e.g. at the bottom of the intersection line between both surfaces contributing to the corner reflection (see bottom of Figure 4). The focused point is only visible due to the fact that building walls have been defined to be transparent. In that case, the point scatterer does not correspond to a real building corner since it has been created by the interaction of the signal and two walls corresponding to different buildings. Again, the height of the focused point is equal to the ground level.

Monitoring this point scatterer over time, e.g. by PS Interferometry, would not mean monitoring one single building. Instead, the deformation information would be composed by the interaction of signals with the ground and two unconnected building walls corre-

sponding to different buildings. Hence, relative movement between the buildings may be mixed into the deformation signal as well.

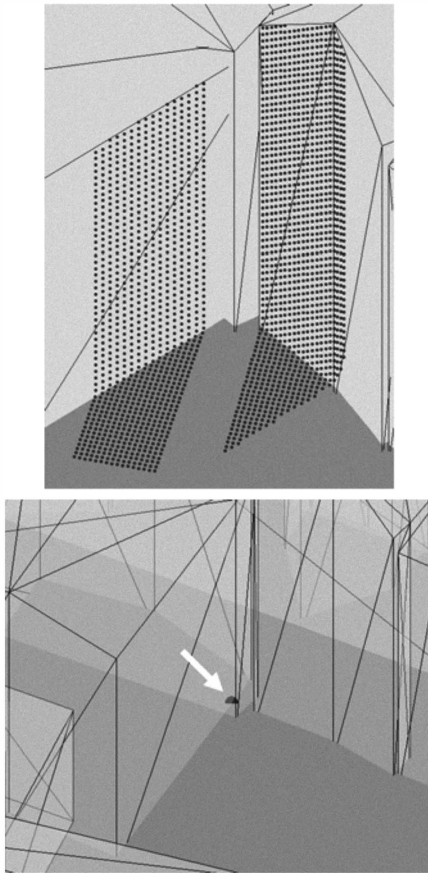


Figure 4: Detected “ghost” corner showing specular backscattering behaviour; top: surfaces contributing to specular highlight; lack of contributions backscattered at the corner center area; bottom: 3D phase center located within building (dark semicircle visible due to transparent walls); focused corner does not correspond to a physical corner of a building.

4. Conclusions & Outlook

In this paper, a concept for visual representation and three-dimensional geometrical analysis of salient scatterers has been presented. Intersection points detected during sampling of a given 3D site scene enable the identification of backscattering surfaces contributing to intensities within selected image pixels. Displaying focused intensities in 3D enables distinguishing between corners corresponding to real building corners and artificial corners situated, for instance, inside buildings. In any case, the nature of salient scatterers has to be further investigated in order to get knowledge about deformation information contained in SAR image pixels.

Future work will concentrate on more profound identification and analysis of scatterers used for PS Inter-

ferometry or SAR Tomography. To this end, real 3D models of buildings have to be used for SAR simulation for detecting trihedrals of smaller size, e.g. appearing at balconies, windows, etc.

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References

- [1] Adam, N., Eineder, M., Yague-Martinez, N., Bamler, R., 2008: High Resolution Interferometric Stacking with TerraSAR-X, In: Proceedings of IGARSS 2008, II-117 - II-120
- [2] Gernhardt, S., Hinz, S., 2008: Advanced Displacement Estimation for PSI using High Resolution SAR Data, In: Proceedings of IGARSS 2008, 3, III -1276-III -1279
- [3] Soergel, U.; Thoennessen, U.; Brenner, A., Stilla, U., 2006: High-resolution SAR data: new opportunities and challenges for the analysis of urban areas, IEE Proceedings - Radar, Sonar and Navigation, 153, 294-300
- [4] Ferretti, A.; Prati, C., Rocca, F., 2001: Permanent scatterers in SAR interferometry, IEEE TGRS, 39, 8-20
- [5] Auer, S.; Hinz, S., Bamler, R., 2009: Ray Tracing Simulation Techniques for Understanding High Resolution SAR Images, IEEE TGRS, online available
- [6] POV Ray, www.povray.org [last access: 19.11.2009], Persistence of Vision Raytracer Propriety Limited
- [7] Auer, S.; Zhu, X.; Hinz, S., Bamler, R., 2009: Ray Tracing and SAR-Tomography for 3D Analysis of Microwave Scattering at Man-Made Objects, CMRT 2009. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 38-3/W4, 157-162
- [8] Reigber, A., Moreira, A., 2000: First demonstration of airborne SAR tomography using multi-baseline L-band data, IEEE TGRS, 38, 2142-2152
- [9] Sarabandi, K., Chiu, T.-C., 1996: Optimum corner reflectors for calibration of imaging radars, IEEE Transactions on Antennas and Propagation, 1996, 44, 1348-1361
- [10] Auer, S.; Hinz, S., Bamler, R. 2008: Ray Tracing for Simulating Reflection Phenomena in SAR Images, In: Proceedings of IGARSS 2008, 5, V - 518-V -521